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THE TUOLUMNE AND OTHER CALIFORNIA RIVERS

LETTER

FROM

THE SECRETARY OF THE INTERIOR

TRANSMITTING,

IN RESPONSE TO A SENATE RESOLUTION OF OCTOBER 31, 1913, CERTAIN INFORMATION RELATIVE TO THE TUOLUMNE, STANISLAUS, MOKELUMNE, AND COSUMNES RIVERS IN CALIFORNIA

8

November 29, 1913.—Ordered to lie on the table and be printed without illustrations

WASHINGTON
1913

UNITED STATES OF AMERICA
GOVERNMENT PRINTING OFFICE

TUOLUMNE AND OTHER CALIFORNIA RIVERS.

THE SECRETARY OF THE INTERIOR,
Washington, November 28, 1913.

MY DEAR MR. VICE PRESIDENT: I have the honor to transmit herewith a report furnished by the chairman of the Board of Army Engineers, and a report from the Director of the Geological Survey, in response to Senate resolution 191, dated October 13, 1913, calling for certain data relative to the Tuolumne, Stanislaus, Mokelumne, and Cosumnes Rivers, in California.

Very truly yours,

FRANKLIN K. LANE.

The VICE PRESIDENT,
Washington, D. C.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF STAFF,
Washington, November 8, 1913.

The SECRETARY OF THE INTERIOR,
Washington, D. C.

SIR: In answer to your communication of October 14, I inclose herewith answers to the information desired by the Senate of the United States in connection with the Hetch Hetchy system of water supply for the city of San Francisco. These answers were prepared by Mr. H. H. Wadsworth, assistant engineer to the Board of Army Engineers, and it is thought that they are reasonably accurate.

In a copy of letter sent to me about October 22 it is stated that the Geological Survey is also preparing answers to these questions. It is therefore suggested that the information herewith be forwarded to that bureau.

Very respectfully,

JOHN BIDDLE,
Colonel, Corps of Engineers,
Chairman of the Board of Army Engineers.

WAR DEPARTMENT,
UNITED STATES ENGINEER OFFICE,
San Francisco, Cal., November 2, 1913.

Col. JOHN BIDDLE,
Corps of Engineers, United States Army,
General Staff, Washington, D. C.

COLONEL: Complying with your request of October 15, I have worked up to the best of my ability within the available time the information requested in Senate resolution 191.

The accompanying Table No. 1 gives the information asked for under the headings first to ninth, inclusive.

Table No. 2 covers the tenth point.

Footnotes are added to both tables, which I think give all the needed explanations and qualifications.

Very respectfully, H. H. WADSWORTH.

TABLE No. 1.

	Tuolumne River above La Grange.	Stanislaus River above Knights Ferry.	Mokelumne River above Clements.	Cosumnes River above Michigan Bar.
Drainage area.....square miles..	1,500	935	642	580
Seasonal (October to September, inclusive) discharge from drainage area, acre-feet:				
1895–96	1,590,000	.....	.....	.....
1896–97	2,440,000	.....	.....	.....
1897–98	960,000	.....	.....	.....
1898–99	1,330,000	.....	.....	.....
1899–1900	1,630,000	.....	.....	.....
1900–1901	2,720,000	.....	.....	.....
1901–2	1,610,000	.....	.....	.....
1902–3	1,970,000	.....	.....	.....
1903–4	2,660,000	2,010,000	.....	.....
1904–5	1,720,000	844,000	.....	.....
1905–6	3,530,000	2,380,000	1,350,000	.....
1906–7	3,760,000	2,800,000	1,670,000	.....
1907–8	1,070,000	593,000	480,000	148,000
1908–9	2,650,000	1,890,000	1,150,000	638,000
1909–10	2,080,000	1,370,000	906,000	463,000
1910–11	3,410,000	2,320,000	1,530,000	874,000
1911–12 [1]	966,000	534,000	371,000	122,000
Total area (acres) of irrigable land that can be irrigated from each river.	410,000	230,000	200,000	90,000
Quantity of water (acre-feet) that can be stored at feasible reservoir sites on the river and its tributaries	1,000,000	[2] 250,000	[3] 234,000	96,000
Quantity of water (acre-feet) that it may be advisable to store for irrigation	200,000	80,000	80,000	([4])
Area of part of total drainage area available for a city water supply, square miles	652	615	438	(?)
Capacity of feasible reservoir sites within above areas after provision is made for irrigation	[5] 800,000 [6] 260,000,000,000	[2] [5] 170,000 [6] 55,000,000,000	[5] 154,000 [6] 50,000,000,000	....
Quantity of water per day that would be available for a city supply	[6] 400,000,000	[6] [7] 57,000,000	[6] 128,000,000	([4])

[1] The discharges given for 1911–12 are for the period from October to June (inclusive) only. Figures for remainder of seasonal run-off should now be available at Washington office of United States Geological Survey.

[2] The total capacity of constructed and proposed reservoirs of Sierra & San Francisco Power Co. on Middle Fork of Stanislaus River is 170,000 acre-feet. There are some reservoir sites of greater or less feasibility on the North Fork and some in the foothills. The 250,000 acre-feet given here includes, therefore, 80,000 acre-feet arbitrary allowance for reservoirs not definitely located.

[3] These 234,000 acre-feet of storage capacity on the Mokelumne include 2 sites on the North Fork, with aggregate capacity of 162,000 acre-feet, neither of which can at present be called entirely feasible on account of excessive cost of dam for the storage effected.

[4] Consideration has heretofore been given to the Cosumnes as a source of city water supply only in connection with the American and then primarily to take advantage of its reservoir sites for American River water. Considered by itself, the water available from Cosumnes is very little.

[5] Acre-feet.

[6] Gallons.

[7] No such thorough study has been made as to the amount of water actually needed or that can be beneficially applied to Stanislaus River lands as distinguished from the extent of appropriations by the irrigation districts, as has been done in the case of the Tuolumne. But with the much smaller amount of storage practicable on the Stanislaus it is very evident that the appropriated waters are needed for beneficial use on the lands.

Could the appropriations of the irrigation districts be disregarded, the Middle Fork of the Stanislaus, with 170,000 acre-feet of storage capacity, would yield through most critical periods 140,000,000 gallons daily.

TABLE No. 2.

	Cherry Valley drainage area.	Lake Eleanor drainage area.	Hetch Hetchy drainage area.
Average discharge for 16 years (1895–1911):			
Acre-feet per year	[1] 231,000	[1] 160,000	[1] 829,000
Gallons per day	206,000,000	143,000,000	741,000,000
Approximate continuous discharge attainable by practicable storage, regardless of prior rights (gallons per day)	160,000,000	130,000,000	550,000,000
Approximate amount of power that may be developed from water from these portions of drainage areas, but with power plants necessarily located below them (horsepower)	59,000	48,000	160,000

[1] The average discharges for the 16 seasons (1895–1911) as given here are the averages of the discharges from the given portions of the Tuolumne River drainage areas as deduced from the discharge at La Grange as described on pages 79 and 80 of the published report of the Advisory Board of Engineers.

The records of measurements made by the city of San Francisco since 1910 give for the season 1910–11 actual discharges greater than the deduced ones by 45 per cent in the case of Cherry Valley, 20 per cent in the case of Lake Eleanor, and in the case of Hetch Hetchy the measured discharge for the period from December to September was 18 per cent greater than the deduced discharge for the whole season.

The mean measured discharge for the three seasons, 1910–1913, which include the two very dry seasons 1911–12 and 1912–13, agrees very closely with the 16-year deduced mean as given above.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
OFFICE OF THE DIRECTOR,
Washington, November 28, 1913.

The SECRETARY OF THE INTERIOR.

SIR: In reply to your letter of October 16, 1913, requesting me to furnish data called for in the resolution of the Senate dated October 13, 1913, text of which follows:

Resolved, That the Secretary of the Interior be, and he is hereby, directed to furnish the Senate with the following information:

First. The drainage area east of La Grange on the Tuolumne River, Cal.

Second. The run-off from such drainage area by years or seasons, and for such a period of time as the records will permit.

Third. The total area of land irrigable or that can be irrigated from this river and for which the waters of the Tuolumne River and tributaries can be put to beneficial use.

Fourth. The quantities of water that can be stored in feasible reservoir sites on the river and its tributary streams.

Fifth. The quantities of water that it is deemed advisable to store for beneficial use of the lands properly irrigable from said stream or tributaries.

Sixth. The drainage area and run-off of such part of said total drainage area as may then be available as a water supply for incorporated cities and towns, the capacities of feasible reservoir sites within said area after provision is made for beneficial use of the lands properly irrigable from these sources, and the quantity of water per day in gallons that would be available as a water supply for such incorporated cities and towns.

Seventh. That he be directed to furnish the same information for the Stanislaus River east of Knights Ferry;

Eighth. For the Mokelumne River east of Clements; and

Ninth. For the Cosumnes River east of Michigan Bar.

Tenth. That the statement include a separate statement of the average annual flow of water in the Cherry, Lake Eleanor, and Hetch Hetchy tributaries of the Tuolumne, and a separate statement of the amount of hydroelectric power capable of being developed in each one of these three tributaries of the Tuolumne.

The Geological Survey has examined all available sources of information bearing upon the questions asked, and the following brief

summary is presented in answer to the specific questions of the resolution:

First. The drainage area east of La Grange on the Tuolumne River is 1,548 square miles.

Second. The mean annual run-off from this drainage area varies in the period of record from 960,000 acre-feet to 3,760,000 acre-feet, with a mean of 2,040,000 acre-feet. The details of the run-off are shown in the hydrograph which accompanies this report.

Third. The total area of land irrigable, or that can be irrigated from this river, and for which the waters of the Tuolumne River and tributaries can be put to beneficial use is 411,520 acres.

Fourth. The quantity of water that can be stored in feasible reservoir sites on the river and its tributary streams is 1,000,000 acre-feet.

Fifth. The quantity of water that it is deemed advisable to store for beneficial use of the lands properly irrigable from this stream or its tributaries is 450,000 acre-feet.

Sixth. (*a*) The part of the total drainage area above given, which is available as a source of water supply for incorporated cities and towns, is the area of the watershed above the confluence of the North Fork with the Tuolumne River, which is 1,257 square miles.

(*b*) The run-off from this area which may then be available (allowance having been made for the requirements for irrigation) as a water supply for incorporated cities and towns, as estimated from existing records of discharge and by comparison of drainage areas, is 961,000 acre-feet per annum, equivalent to 858,000,000 gallons per day.

(*c*) The aggregate capacity of feasible reservoir sites within said area after provision is made for beneficial use of the lands properly irrigable from this source, is 550,000 acre-feet.

(*d*) The quantity of water that would be available as a water supply for such incorporated cities and towns by the use of such feasible reservoir sites within said area, and after provision is made for beneficial use of the lands properly irrigable from this source, is, in the lowest period of record (1912–13), 230,000,000 gallons per day.

Seventh. 1. The drainage area east of Knights Ferry on the Stanislaus River is 1,035 square miles.

2. The mean annual run-off from this drainage area varies in the period of record from 370,000 acre-feet, to 2,800,000 acre-feet, with a mean of 1,380,000 acre-feet. The details of the run-off are shown in the hydrograph which accompanies this report.

3. The total area of land irrigable, or that can be irrigated from this river, and for which the waters of the Stanislaus River and tributaries can be put to beneficial use is 240,000 acres.

4. The quantity of water that can be stored in feasible reservoir sites on the river and its tributary streams is 550,000 acre-feet.

5. The quantity of water that it is deemed advisable to store for beneficial use of the lands properly irrigable from this stream or its tributaries is 300,000 acre-feet.

6. (*a*) The part of the total drainage area above given, which is available as a source of water supply for incorporated cities and towns, is the area of the watershed above Robinson on the Stanislaus River, which is 827 square miles.

(*b*) The run-off from this area which may then be available (allowance having been made for the requirements for irrigation) as a water supply for incorporated cities and towns, as estimated from existing records of discharge and by comparison of drainage areas, is 750,000 acre-feet per annum, equivalent to 669,000,000 gallons per day.

(*c*) The aggregate capacity of feasible reservoir sites within said area, after provision is made for beneficial use of the land properly irrigable from this source, is 250,000 acre-feet.

(*d*) The quantity of water that would be available as a water supply for such incorporated cities and towns by the use of such feasible reservoir sites within said area, and after provision is made for beneficial use of the lands properly irrigable from this source, is, in the lowest period of record (1912–13), 100,000,000 gallons per day.

Eighth. 1. The drainage area east of Clements on the Mokelumne River, is 631 square miles.

2. The mean annual run-off from this drainage area varies in the period of record from 393,000 acre-feet to 1,670,000 acre-feet, with a mean of 880,000 acre-feet. The details of the run-off are shown in the hydrograph which accompanies this report.

3. The total area of land irrigable, or that can be irrigated from this river, and for which the waters of the Mokelumne River and tributaries can be put to beneficial use, is 225,000 acres.

4. The quantity of water that can be stored in feasible reservoir sites on the river and its tributary streams is 200,000 acre-feet.

5. The quantity of water that it is deemed advisable to store for beneficial use of the lands properly irrigable from this stream or its tributaries is 200,000 acre-feet.

6. (*a*) The part of the total drainage area above given, which is available as a source of water supply for incorporated cities and towns, is the area of the watershed above Electra on the Mokelumne River, which is 532 square miles.

(*b*) The run-off from this area which may then be available (allowance having been made for the requirements for irrigation) as a water supply for incorporated cities and towns, as estimated from existing records of discharge and by comparison of drainage areas, is 287,500 acre-feet per annum, equivalent to 257,000,000 gallons per day.

(*c*) After provision is made for beneficial use of the land properly irrigable from this source no feasible reservoir sites within this area will be available for water supply of incorporated cities and towns.

(*d*) After provision is made for beneficial use of the lands properly irrigable from this source no water would be available as a water supply for incorporated cities and towns.

Ninth. 1. The drainage area east of Michigan Bar on the Cosumnes River is 536 square miles.

2. The mean annual run-off from this drainage area varies in the period of record from 127,000 acre-feet to 874,000 acre-feet, with a mean of 400,000 acre-feet. The details of the run-off are shown in the hydrograph which accompanies this report.

3. The total area of land irrigable, or that can be irrigated from this river, and for which the waters of the Cosumnes River and tributaries can be put to beneficial use, is 100,000 acres.

4. The quantity of water that can be stored in feasible reservoir sites on the river and its tributary streams is 125,000 acre-feet.

5. The quantity of water that it is deemed advisable to store for beneficial use of the lands properly irrigable from this stream or its tributaries is 125,000 acre-feet.

6. (*a*) Because of the lack of sufficient storage reservoirs none of the drainage area above given is available as a source of water supply for incorporated cities and towns.

(*b*) The run-off from this area which may then be available (allowance having been made for the requirements for irrigation) as a water supply for incorporated cities and towns, as estimated from existing records of discharge and by comparison of drainage areas, is 130,000 acre-feet per annum, equivalent to 112,000,000 gallons per day.

(*c*) After provision is made for beneficial use of the land properly irrigable from this source no feasible reservoir sites within this area will be available for water supply for incorporated cities and towns.

(*d*) After provision is made for beneficial use of the land properly irrigable from this source no water would be available as a water supply for incorporated cities and towns.

Tenth. (*a*) The average annual flow of Cherry Creek at Groveland is 295,000 acre-feet.

(*b*) The average annual flow of Eleanor Creek at Groveland is 146,000 acre-feet.

(*c*) The average annual flow of Tuolumne River at the Hetch Hetchy Reservoir site is 805,000 acre-feet.

(*d*) Data are not available upon which to base estimates of the power possibilities in the drainage areas of these streams under the conditions imposed by the resolution.

GENERAL STATEMENT.

The following statement is made for the purpose of indicating the methods by which the conclusions above expressed have been reached and in order that the sources of information used and the methods of analysis adopted by the engineers of the Geological Survey in reaching these conclusions may be followed by other engineers who may desire to consider the data upon which the conclusions rest. In order that the results obtained may be as nearly comparable as possible, the Geological Survey has endeavored to analyze the water supply of each stream by the same methods, and has assumed the same duty of water for irrigation of the lands under each source of supply and the same distribution of this water throughout the irrigation season.

The fundamental data upon which conclusions of this character must rest are somewhat more satisfactory in the case of the Tuolumne River than in the other streams discussed. Not only is the record of stream flow of the Tuolumne longer and more complete, but the data relating to reservoir sites in the drainage basin of the Tuolumne are based on more careful determinations of capacities than those in the other drainage basins. This has doubtless been due in large measure to the fact that the city of San Francisco has made thorough studies of reservoir sites on the Tuolumne.

DRAINAGE AREAS.

The drainage areas given for each of the aforesaid streams are based on new and careful measurements made on topographic sheets of the Geological Survey. These new computations show differences from those published in Water-Supply Paper No. 299 on the water supply of California, as follows:

Drainage areas of streams in San Joaquin Basin.

Streams.	New area.	Old area.	Difference.
	Square miles.	*Square miles.*	*Square miles.*
Tuolumne River at La Grange Dam	1,548.0	1,500.0	+ 48.0
Tuolumne River at Hetch Hetchy Dam site	460	.....	.....
Stanislaus River at Knights Ferry	1,035	935	+100
Middle Fork Stanislaus River at Sand Bar Flat	327	.....	.....
Mokelumne River at Clements	631	642	− 11
Cosumnes River at Michigan Bar	536	524	+ 12
Eleanor Creek at gauging station	77.3	.....	.....
Cherry Creek at gauging station	112	.....	.....
Tuolumne River below North Fork	1,252	.....	.....
Stanislaus River at Robinson	827	.....	.....
Mokelumne River above Electra	532	.....	.....
Eleanor Creek at dam site	78.3	.....	.....
Cherry Creek at dam site	116.6	.....	.....

These differences are due to the fact that more accurate maps are now available than at the time the original measurements of area were made some years ago, and the methods of measurement are believed to be more accurate.

RUN-OFF.

The following table with accompanying footnotes shows the annual run-off by years from October 1 to September 30 for the periods of record on each stream. In addition thereto, certain gaps in the record have been filled by comparison with similar periods on the other streams, for the purpose of securing records of practically the same length on each stream, by the use of which a mean annual run-off could be computed, based upon the same period of years in each case. The estimated amounts for such periods are stated in a footnote to the table. These records have been brought down to September 30, 1913, by securing from the field for the purposes of this report the unpublished records and computations to the end of the last quarter.

Table of annual discharge.

	Tuolumne.	Stanislaus.	Mokelumne.	Cosumnes.
November, 1878–October, 1879	1,450,000	1,300,000	819,000	.....
November, 1879–October, 1880	2,630,000	1,630,000	1,260,000	.....
November, 1880–October, 1881	2,090,000	1,450,000	802,000	.....
November, 1881–October, 1882	1,600,000	1,480,000	908,000	.....
November, 1882–October, 1883	1,450,000	935,000	690,000	.....
November, 1883–October, 1884	2,410,000	1,710,000	1,210,000	.....
September, 1895	(15,635)	.....	.....	.....
June, 1895–September, 1895	.....	(506,000)	.....	.....
October, 1895–September, 1896	1,590,000	1,340,000	.....	.....
October, 1896–September, 1897	2,440,000	1,370,000	.....	.....
October, 1897–September, 1898	960,000	370,000	.....	.....
October, 1898–September, 1899	1,330,000	785,000	.....	.....
October, 1899–September, 1900	1,630,000	894,000	.....	.....
October, 1900–September, 1901	2,720,000	(153,700)	(1,030,000)	.....
October, 1901–September, 1902	1,610,000	.....	(62,600)	.....
October, 1902–September, 1903	1,970,000	(479,000)	(200,500)	.....
October, 1903–September, 1904	2,660,000	2,010,000	1,320,000	.....
October, 1904–September, 1905	1,720,000	944,000	641,500	.....
October, 1905–September, 1906	3,530,000	2,380,000	1,350,000	.....
October, 1906–September, 1907	3,760,000	2,800,000	1,670,000	.....
October, 1907–September, 1908	1,070,000	593,000	480,000	148,000
October, 1908–September, 1909	2,650,000	1,890,000	1,150,000	638,000
October, 1909–September, 1910	2,080,000	1,370,000	906,000	463,000
October, 1910–September, 1911	3,410,000	2,320,000	1,530,000	874,000
October, 1911–September, 1912	1,050,000	587,000	393,000	139,000
October, 1912–September, 1913	1,080,000	554,000	423,000	127,000

NOTES.—Additional periods of run-off were estimated by comparison with adjacent drainage basins as follows:

Stanislaus, January, 1901–April, 1903	3,163,000
Mokelumne, October, 1895–December, 1900	3,120,000
Mokelumne, January, 1901–May, 1903	2,200,000

By including these estimated periods in the record above given the following estimates of mean annual run-off for the 24-year period represented by the above record were obtained:

Tuolumne	2,040,000
Stanislaus	1,380,000
Mokelumne	880,000
Cosumnes (6 years)	400,000

Fractional years are inclosed in brackets.

Tuolumne River measurements were made at the following stations:

Modesto station: Period November, 1878–October, 1884; drainage area above station, 1,635 square miles. Measurements published in United States Geological Survey Water-Supply Paper 299, pp. 298, 299.

Lagrange station: Period January, 1895–September, 1913; drainage area above station, 1,548 square miles. Measurements published in Water-Supply Paper 299, pp. 267–270.

Stanislaus River measurements made at the following stations:

Oakdale station: Period November, 1878–October, 1884; drainage area above station, 1,051 square miles. Measurements published in Water-Supply Paper 299, pp. 342, 343.

Oakdale station: Period June, 1895–December, 1900; drainage area above station, 1,051 square miles. Measurements published in Water-Supply Paper 299, pp. 348, 349.

Knights Ferry station: Period May, 1903–September, 1913; drainage area above station, 1,035 square miles. Measurements published in Water-Supply Paper 299, pp. 339–341.

Mokelumne River measurements were made at the following stations:

Lone Star Mill station: Period November, 1878–October, 1884; drainage area above station, 657 square miles. Measurements published in Water-Supply Paper 299, pp. 373, 374.

Electra station: Periods January–December, 1901; June, 1903–December, 1904; drainage area above station, 537 square miles. Measurements published in Water-Supply Paper 299, p. 372.

Clements station: Period January, 1905–September, 1913; drainage area above station, 631 square miles. Measurements published in Water-Supply Paper 299, pp. 383, 384.

Cosumnes River measurements were made at the following stations:

Michigan Bar station: Period October, 1907–September, 1913; drainage area above station, 536 square miles. Measurements published in Water-Supply Paper 299, p. 402.

Live Oak Suspension Bridge station: Period November, 1878–October, 1884; was based entirely on comparison with adjacent drainage areas. The figures published for this station in Water-Supply Paper 299, pp. 403, 404, have not been used in making estimates for this report. As compared with the run-off data obtained at the Michigan Bar station the early estimates appear to be excessive.

IRRIGABLE AREAS.

The areas irrigable under the four rivers named in the resolution are not defined by physical boundaries, except San Joaquin River on the west, and even that may in the future be crossed by siphons to conduct water from the rivers on the east to the arid lands on the west. The construction of irrigation systems has, however, to a certain

degree, defined the areas which are now and may in the future be irrigated from each source of supply.

The great valley of California occupies a central depression, lying between the Sierra Nevada on the east and the coast ranges on the west and extending through about half the length of the State. The valley drains to the west into San Francisco Bay through a break in the coast ranges at about the middle of its western side. Sacramento River drains the northern portion of the valley, roughly following its axis from northwest to southeast, and, similarly, San Joaquin River drains the southern portion of the valley. The two rivers unite near Suisun Bay. Whereas Sacramento River traverses practically the entire length of Sacramento Valley, San Joaquin River enters San Joaquin Valley at a point somewhat over halfway south along its eastern border.

The four streams named in the resolution enter the northern portion of San Joaquin Valley and the southern portion of Sacramento Valley from the east in the region extending southward from a point approximately opposite San Francisco Bay.

The portion of San Joaquin Valley south of San Joaquin River itself has as its principal sources of water supply Kings, Kaweah, Tulare, and Kern Rivers, all of which streams have their sources upon the crest of the Sierra Nevada. All streams which enter San Joaquin Valley from the west have small drainage areas and are practically all intermittent in character, so that the water supply derived from the western side of the valley is negligible. The portion of San Joaquin Valley south of San Joaquin River has no surface outlet under ordinary conditions, and the surplus waters of this portion of the valley reach Tulare Lake. This lake has not in recent years, or since any large amount of water has been used for irrigation, attained a sufficiently high stage to overflow to the San Joaquin River. Northward from the area drained by the four streams under discussion, the Sacramento receives a number of large tributaries from the east. The American enters a short distance north of the Cosumnes, the Bear about 30 miles north of the American, and the Yuba and Feather still farther north. American River is a much larger stream than either of the four rivers named in the resolution, and discharges more water than all four combined. Its discharge is much in excess of any possible irrigation use for which there is land available. Feather, Yuba, and Bear Rivers also carry large amounts of water in excess of any irrigation demand.

The area which must then be considered in relation to irrigation from the Tuolumne, Stanislaus, Mokelumne, and Cosumnes Rivers lies in that part of the great valley between American River on the north and San Joaquin River on the south.

The western limit of irrigation from these streams is somewhat less definite, since data do not exist by which it is possible to delimit the portions of San Joaquin Valley adjacent to San Joaquin River which it may ultimately prove most economical to supply by pumping from the underflow. It is possible also that portions of the flow of these streams might be carried across San Joaquin Valley by siphons or otherwise, and used upon lands situated west of the river, but again no data are available upon which to base proper and definite conclusions in this regard. For the purpose of this report, then, the area which it is considered possible to irrigate from these sources has been

confined to the east of San Joaquin River, no attempt having been made to draw a close line between lands to be supplied by gravity and lands susceptible of irrigation by pumping from the underflow.

In addition to the four streams named, the area so delimited receives additional water supply for irrigation from Merced and Calaveras Rivers and from the minor streams Chowchilla and Fresno Rivers, Mariposa and Bear Creeks, besides San Joaquin River itself. With the exception of the Calaveras, these streams all lie to the south of Tuolumne River, and are the only sources of water supply between that stream and the San Joaquin.

The third question in the resolution is interpreted by the Geological Survey as calling for a statement of the areas which, under an orderly and complete irrigation development of that portion of San Joaquin Valley above described, would properly be irrigated from Tuolumne River. Subsequent questions call for similar data for the other streams. The problem, then, resolves itself into a determination of the areas adjacent to these streams which it is thought are feasible of irrigation and the amount of land which under normal conditions of complete irrigation development would be assigned to each stream, due consideration being given to existing irrigation systems and the land which they cover. This last factor—existing development—demarks more closely than any other the areas which should be regarded as properly irrigable from each of the streams mentioned, especially from Tuolumne and Stanislaus Rivers since there are no topographic conditions which clearly delimit the areas properly irrigable from these streams. It is entirely possible for areas now irrigated by either the Stanislaus or the Tuolumne to be transferred to and irrigated from the other stream, and, in fact, in the past such transfer of water rights has actually occurred.

Mean annual run-off.—The following table gives the mean annual run-off of streams entering the great valley discussed in this report, as estimated from the stream-gauging records of the Geological Survey.

Mean annual run-off of streams entering San Joaquin and Sacramento Valleys.

Name of stream.	Period of record.	Years.	Mean annual run-off.
			Acre-feet.
Kings River	1878–1884, 1895–1912	23	1,900,000
San Joaquin River	1878–1884, 1895–1901, 1907–1913	18	2,100.000
Fresno River	1878–1879, 1911–1912	2	50,000
Chowchilla Creek	1878–1880	2	50,000
Mariposa Creek	No measurements		15,000
Bear Creek	1878–1881	3	23,000
Merced River	1878–1884, 1901–1912	17	1.150,000
Tuolumne River	1878–1884, 1895–1913	24	2,040,000
Stanislaus River	1878–1884, 1895–1900, 1903–1913	21	1,380,000
Calaveras River	1878–1879, 1907–1912	7	
Mokelumne River	1878–1884, 1901, 1903–1913	17	880,000
Cosumnes River	1907–1913	6	400,000
American River	1904–1912	8	5,100,000
Bear River	1904–1912	8	400.000

In calculating the mean annual run-off of the San Joaquin, Merced, Stanislaus, and Mokelumne Rivers, certain missing periods in each record were supplied by comparison with adjacent drainage basins, so that the mean annual run-off figures given above for these streams are averages of 23 or 24 year periods, in part estimated.

Tuolumne River.—The area properly irrigable from Tuolumne River has been arrived at in the following manner:

It has been assumed first that because of the extreme scarcity of water supply south of the Merced, that stream will in the future, as at present, be used practically in its entirety south of the channel of the stream. North of the Tuolumne the line of demarcation between the area to be served by the Stanislaus and that to be served by the Tuolumne has been drawn at the boundary between the Oakdale and South San Joaquin districts on the north, which now derive their water supply from Stanislaus River, and the Modesto district on the south, which is now irrigated from Tuolumne River. It has been assumed that the land which lies east of the Oakdale district and north of the Modesto Canal and which are not now irrigated will in future be most economically irrigated from Stanislaus River, hence the division line between the areas to be irrigated from those two streams practically follows the Modesto Canal. On the other hand, a large area of dry land lying east of Turlock irrigation district and north of Merced River has been regarded as properly irrigable from Tuolumne River. This arrangement, then, assigns to Tuolumne River the area now included in the Modesto irrigation district, 81,143 acres, and the Turlock district, 176,210 acres. The unirrigated area comprises 241 square miles additional, a total of 643 square miles, equivalent to 411,520 acres.

This area is slightly less than that regarded as properly irrigable from Tuolumne River by the conservation commission of the State of California. In its report on irrigation, issued in 1912, the following statement is made on page 217:

> This division (the Modesto-Turlock area) includes the valley and plains for which the Tuolumne River is the most natural source of supply. It extends from the Merced River on the south to the Stanislaus River on the north, excluding only a part of the plains area north of Dry Creek now largely included in the Oakdale irrigation district. The total area is 450,000 acres, of which 315,000 acres are classed as valley land and 135,000 acres as plains. Of the valley land, 22,500 acres consist of lowlands along the San Joaquin River and outside of the irrigation districts which are subject to more or less overflow, and about 14,000 acres along the Tuolumne and Stanislaus Rivers.

In the report of H. S. Crowe and Burton Smith, engineers for the Turlock and Modesto irrigation districts, submitted to the Advisory Board of Army Engineers on November 1, 1912, the following statement is made on page 144:

> Large areas of land tributary to the districts and within reach of the Tuolumne River are wholly dependent upon the waters of this stream for their reclamation. The absence of united effort for their defense is only natural under the conditions, but this renders their claim none the less deserving of careful recognition. The situation in the San Joaquin Valley in regard to the rights of its arid agricultural lands is in this connection quite analogous to the rights of a minor who, in the absence of parental protection, is guarded by the public because he is unable to protect himself. His inability to assert his rights does not relieve the public of its responsibility. The burden of defense for the San Joaquin Valley should be borne by the State, but much aid can be given at this time by the Federal Government. The importance of having full information concerning the irrigation possibilities in this part of the San Joaquin Valley can not be overestimated. We are unable at this time to show the irrigable agricultural lands now unreclaimed.

Mr. J. H. Dockweiler, in his report made for the city of San Francisco on the needs of the Modesto and Turlock irrigation districts, considers only the areas of those districts as now constituted. (A total of 402 square miles, or 257,353 acres.) This area Dockweiler reduces by 20 per cent to allow for nonuse, and estimates the water requirements for a net area of 206,000 acres.

In the report of the Advisory Board of Army Engineers to the Secretary of the Interior on investigations relative to sources of water supply for San Francisco and bay communities, dated February 19, 1913, page 105, Mr. H. H. Wadsworth, assistant engineer, makes the following statement regarding this question:

Six hundred and forty-three square miles is considered a generous estimate of the area dependent on the Tuolumne for water. * * *

It may quite possibly be that the area outside of Turlock and Modesto districts, estimated above as dependent on the Tuolumne for water, is somewhat too large, but if so, there is a thirsty area on the west side of San Joaquin, to which excess water could be piped and where it could be advantageously used. It is probable, however, that the present practice of irrigating such of the west side lands as cannot be reached by gravity ditches, viz., by pumping from the San Joaquin River, is the more economical.

With increased use and better distribution of water on the east side, made possible by storage, the seepage back into the river will increase the supply available for such pumping.

For this investigation, no change has been made in the area, as noted above, which might properly be irrigated from the Tuolumne.

The area assumed by the Survey for this report is the same as that assumed by Mr. Wadsworth.

Stanislaus River.—In estimating the area properly irrigable from Stanislaus River, boundaries have been assumed as follows: The line of demarcation on the south, as stated under the discussion of the Tuolumne River, is drawn north and east of the Modesto irrigation district and canal. The northern boundary of the area to which the water supply of Stanislaus River is properly tributary is drawn at Camp Creek, somewhat north of the northern boundary of the South San Joaquin irrigation district as at present organized. The area, then, includes the South San Joaquin and Oakdale irrigation districts, together with an area lying east of and higher than the Oakdale district between Stanislaus and Tuolumne Rivers, and an area lying north of the South San Joaquin and Oakdale irrigation districts. The total area has been taken for the purposes of this report as 240,000 acres. Of this total area 72,000 acres are now included in the Oakdale district and 71,000 acres in the South San Joaquin district.

For purposes of comparison with this estimate, quotation is made from the report of the California Conservation Commission, above referred to, page 219:

This area covers the lands most feasibly irrigated from the Stanislaus River. This area extends from the Modesto-Turlock area north to the Mount Diablo base line and includes the South San Joaquin and Oakdale irrigation districts, which are now constructing new irrigation systems which will reclaim the greater part of their areas. The area included covers 129,000 acres of valley and 110,000 acres of plains, a considerable portion of the latter being an even second bench that is very similar in character to the valley land. * * * The irrigation of areas lying north of that at present included in the district is probably physically feasible if a water supply can be provided. The joint canal of the two districts is to have a capacity of 1,700 cubic feet per second, which will require more than the full flow of the stream after June in normal years. The extent to which other areas can be supplied during the later irrigation seasons depends on the storage that can be provided. No large reservoir sites are known and the total amount which it will be practicable to store will probably be less than on the other streams, although it should be possible to supply more than the present 140,000 acres included in the two districts.

Mr. C. E. Grunsky, consulting engineer, in his report upon the Stanislaus River project as a water supply for San Francisco, incorporated as Appendix No. 10 in the report of John R. Freeman to the mayor of San Francisco dated July 15, 1912, states on page 305:

At the present time canals are being constructed by the San Joaquin irrigation district for the irrigation of 71,000 acres of land lying in San Joaquin Valley north of Stanislaus River and by the Oakdale irrigation district for the irrigation on the same side of the river of an additional 24,000 acres and of 48,000 acres on the south side of the Stanislaus, a total of 143,000 acres.

Mr. H. H. Wadsworth, in his report of January 17, 1913, to the Board of Army Engineers, gives no definite estimate of the acreage properly irrigable from the Stanislaus, but on page 102 makes the following statement as to the irrigation demand upon that stream:

Two irrigation districts, the Oakdale and the South San Joaquin, claim the natural flow of the river up to 1,700 cubic feet per second. These districts are now constructing works to enable them to use the water to much better advantage than heretofore. Other small appropriations bring the total well up toward the 2,000 second-feet allowed in computing quantities for mass diagrams of water which might be made available for the use of San Francisco.

Mr. Wadsworth, in his report dated November 2, 1913, made in response to this resolution, has estimated the total area irrigable from Stanislaus River at 230,000 acres.

Mokelumne River.—The area properly irrigable from Mokelumne River includes the area lying south of Dry Creek and north of Calaveras River between the foothills on the east and what is commonly known as the San Joaquin Delta on the west. The area thus bounded includes approximately 225,000 acres, of which only about 30,000 acres are now irrigated by gravity canals from the river. This arrangement assigns to the Calaveras River the area lying between it and Camp Creek. The following quotation is made from the report of the Conservation Commission of California, page 221:

But one system, that of the Stockton and Mokelumne Canal Co., diverts water from Mokelumne River. This canal covers about 32,000 acres lying east of Stockton and Lodi, of which but 2,200 acres are receiving water at present. * * * There are large areas of valley land lying east of the Stockton and Mokelumne Canal which are susceptible of irrigation by gravity from Mokelumne River. Many pumping plants are operating in this area, and the number is being rapidly extended. Any extended use of the Mokelumne will require storage. Reservoir sites are at present known which are estimated to have a capacity of 180,000 acre-feet. The benefits of irrigation are becoming better appreciated and further use of the water of this stream is probable.

Mr. C. E. Grunsky, in Appendix No. 18 to the report of John R. Freeman, page 365, states:

The valley land, which is naturally dependent on the flow of this river for irrigation water, extends from the old bed of Calaveras River northerly to some point between Dry Creek and the Cosumnes River. This is a region of great promise, but there has been very little concerted action thus far to make the river water which now flows to waste available for irrigation. Fertility of soil, a fair amount of rain, and topographic features, which make diversion of water near the base of the mountain more than ordinarily expensive, have apparently been the causes which have delayed the construction of large irrigation works, such as are now being constructed for the irrigation of lands on both sides of the Stanislaus River and as have come into use for the irrigation of the Turlock and Modesto irrigation districts on both sides of the Tuolumne River.

Mr. Wadsworth, in his published report to the Advisory Board of Army Engineers, page 98, states:

Mr. Grunsky's report, submitted August 1, 1912, takes up the subject of irrigation needs of the district that would properly be served by the Mokelumne. He estimates that there are 200,000 acres, requiring 600,000 acre-feet of water annually.

Mr. Wadsworth, in his report of November 2, 1913, in response to this resolution, has estimated the irrigable area under this river at 200,000 acres.

Cosumnes River.—In view of the fact that American River, which lies just north of the Cosumnes, is a stream with a mean annual flow largely in excess of probable irrigation demands, the area which is assumed to be properly irrigable from Cosumnes River in a scheme for the complete development of the San Joaquin Valley has been limited to that portion of the valley which lies south of Cosumnes River and north of Dry Creek. The total amount of this area which is susceptible of irrigation at a reasonable cost can not be accurately estimated from existing data, but for the purposes of this report an estimate of the irrigable acreage at 100,000 acres is believed to be sufficiently accurate. Mr. Wadsworth, in his report of November 2, 1913, in response to this resolution, has estimated this area at 90,000 acres. The report prepared by Mr. J. H. Dockweiler upon the American-Cosumnes project as a source of water supply for the San Francisco Bay region considers the American and Cosumnes Rivers jointly and estimates the gross area requiring irrigation from both streams at 657,996 acres. In considering irrigation requirements Mr. Dockweiler does not attempt to segregate the portion of this area to be supplied from Cosumnes River. Mr. Freeman's conclusions concerning the stream are based on Mr. Dockweiler's report, and likewise do not consider the Cosumnes apart from the American.

FEASIBLE RESERVOIR SITES.

The feasibility of reservoir sites can not be generally determined except in connection with a particular proposed scheme of development wherein the construction cost can be balanced against the value of the developed site. In deciding upon the feasibility of reservoirs in these drainage basins all sites which by reason of ratio of storage capacity to size of dam are comparable to reservoirs already developed for municipal use have been regarded as feasible for the purpose of this report, since it is not possible to determine upon any specific scheme of development in which such reservoirs might be used, and it is, of course, impossible at this time to determine which sites will be most economical or which will be developed for irrigation or for municipal water supplies.

On this basis the following reservoirs have either been constructed or are proposed for development in the drainage basins of the streams:

Tuolumne River.

CONSTRUCTED AND UNDER CONSTRUCTION.

	Height of dam.	Quantity of water that can be stored.
	Feet.	*Acre-feet.*
Modesto		30,000
Alfred Davis		50,000
Phœnix		
PROPOSED.		
Rogers Bar	300	250,000
Hetch Hetchy	300	344,000
Lake Eleanor	200	150,000
Cherry Valley	135	56,800
Vernon Lake	125	36,900
Poopenaut Valley	235	52,100
Tuolumne Meadows	75	43,200

The total capacity indicated for these reservoirs is about 1,000,000 acre-feet, which has been assumed in this report as the total available capacity of feasible reservoir sites on Tuolumne River. In addition there are, however, many small lakes and valleys in the headwaters of this river which are available for development as reservoir sites of small capacity and which may in the future be feasible of construction for power purposes, the power sites being generally located between such small reservoir sites and the larger reservoir sites listed above.

Stanislaus River.

CONSTRUCTED OR UNDER CONSTRUCTION.

	Height of dam.	Quantity of water that can be stored.
	Feet.	*Acre-feet.*
Silver Valley		4,600
Utica		4,600
Union		1,900
Bear Valley		
Relief		24,800
Lower Highland		
Upper Kennedy		50,400
Sand Flat		
Lyons		6,000
Lower Strawberry		3,700
District		101,000

PROPOSED.

Kuhns Meadow		9,200
Lower Kennedy	150	17,400
Donalds Flat	260	53,500
Miller		
Fairplay	110	9,900
Hales		
Robinson	300	250,000
Big Dam	95	15,000

The total capacity indicated for these reservoirs is about 550,000 acre-feet, which has been assumed in this report as the total available capacity of feasible reservoir sites on Stanislaus River. With the exception of Robinson and District Reservoirs, located in the foothills, these reservoirs are located in the upper part of the drainage area of the river, and many of the smaller ones are in the extreme headwaters and are comparable with many sites not listed in the Tuolumne Basin on account of their lack of importance for purposes of irrigation or water supply because of the size and location of Rogers Bar, Hetch Hetchy, Lake Eleanor, Cherry Valley, and other large reservoirs. The reservoir site described at Robinson is comparable in situation and value for irrigation development with that described on the Tuolumne River at Rogers Bar. Unlike the Rogers Bar site, however, it is located at sufficient elevation to serve also as an intake for water supply for municipal purposes.

Mokelumne River.

PROPOSED.

	Height of dam.	Quantity of water that can be stored.
	Feet.	*Acre-feet.*
Railroad Flat	325	69,700
North Fork	325	82,140
North Fork of Middle Fork	110	5,000
Upper Bear River	80	6,100
Lower Bear River	70	4,180
Upper Blue Lake	31	6,700
Lower Blue Lake	40	4,700
Deer Valley	105	7,200
Meadow Lake	54	5,600
Grouse Valley	70	2,380
Snow Valley	70	2,180
Twin Lakes	22	1,420
Hermit Valley	40	1,120

The total capacity indicated for these reservoirs is about 200,000 acre-feet, which has been assumed in this report as the total available capacity of feasible reservoir sites on Mokelumne River. As in the cases of the Tuolumne and Stanislaus, there are in addition many small sites in the extreme headwaters of Mokelumne River which are not listed but which may in the future be valuable for high-head power development.

Cosumnes River.

PROPOSED.

	Height of dam.	Quantity of water that can be stored.
	Feet.	*Acre-feet.*
Bucks Bar	287	55,200
Pleasant Valley	140	13,800
Sly Park	171	32,800
Granite Basin	145	8,000
Capps Crossing	145	9,500
Plummers Ranch	120	2,500
Case Valley	.....	.....

The total capacity indicated from these reservoirs is about 125,000 acre-feet, which has been assumed in this report as the total available capacity of feasible reservoir sites on Cosumnes River.

STORAGE FOR IRRIGATION.

In determining the quantities of water that it is deemed advisable to store for beneficial use for lands properly irrigable from each of the streams described, the irrigable acreages as above explained have been taken, as follows:

	Acres.
Tuolumne River	411,520
Stanislaus River	240,000
Mokelumne River	225,000
Cosumnes River	100,000

Duty of water.—Since irrigation conditions under all of these streams are essentially identical, it is believed that a duty of water

which will adequately irrigate the lands under one stream should be taken as a basis of estimate in computing the amount of irrigation demand on the other streams. Accordingly, for the purposes of this discussion, the irrigation duty has been assumed at 2.5 acre-feet of water for the gross acreage of irrigable land measured at the point of diversion from the stream. No scientific determination of the probable duty of water in this locality has, so far as known to the Geological Survey, been made. It is, therefore, necessary to base estimates largely on the opinions of engineers who have made studies in this general region and upon measurements of the actual irrigation use of water in areas already developed. Mr. H. H. Wadsworth, in his report to the advisory board of Army engineers, submitted January 17, 1913, estimated, on page 106, the duty of water for areas irrigable from Tuolumne River as follows:

> Assuming that 85 per cent of the land will in time be irrigated, allowing for roads, buildings, corrals, etc., and that there may be a 15 per cent loss by seepage and evaporation in ditches, 2½ feet depth for the total acreage, measured at headgates, will suffice.

This, however, is not Mr. Wadsworth's total allowance for irrigation. He further says:

> Two and one-half feet depth over 643 square miles amounts to 1,028,800 acre-feet, or allowing 10 per cent for evaporation from reservoirs and other losses above headgates, or elsewhere, not covered by 15 per cent allowance previously made, the total annual need will be 1,132,000 acre-feet.

He states also that this quantity—

> is based on 2.5 feet depth over 85 per cent of 643 square miles area, with total loss by evaporation and seepage of 23 per cent.

Mr. John R. Freeman, in his report of July 15, 1912, page 101, refers to the investigation of irrigation demands upon Tuolumne River made by Mr. J. H. Dockweiler, and quoted below, stating also that the irrigation priorities at La Grange aggregate 2,410 second-feet.

Mr. Dockweiler assumes (p. 176 of his report of Jan. 29, 1912) that—

> These districts (Modesto and Turlock) cover 257,353 acres, or 402 square miles. Not over 80 per cent of this area—206,000 acres—will be irrigated in any one year. * * * Each acre is to receive 2½ acre-feet as follows: Two and one-fourth from the Tuolumne River and one-fourth from recovery water, drainage pumping into the laterals of the district.

He allows also 15 per cent for seepage losses in canals and laterals, and—

> In the event that storage is drawn from the present and proposed reservoirs of the districts below La Grange Dam, 8 per cent is to be added to the above quantity of water.

Engineers H. S. Crowe and Burton Smith, in reporting for the Modesto and Turlock irrigation districts, assume a minimum net depth of water required for irrigation of the lands of the districts at 2.75 feet of water over the area irrigated, which is taken as 90 per cent of the gross area.

Mr. Cyril Williams, jr., in his report of July 30, 1912, on the water yield of the upper Tuolumne watershed, page 2, says:

> Under the Garfield permit the Turlock-Modesto irrigation districts are entitled to a combined diversion up to 2,350 second-feet, and this in combination with our estimate of 60 second-feet at La Grange (for power purposes,) is equivalent to 568,305,000,000 gallons per year, or over 80 per cent of the average annual flow of the river for 16 years.

The future requirements of these districts is liberally placed at about 173.774,000,000 gallons per annum, and with an additional requirement of 60 cubic feet per second the total diversion would be about 188,000,000,000 gallons.

Mr. C. E. Grunsky, consulting engineer, in his report of July, 1912, upon the Mokelumne as a source of water supply for San Francisco, page 19, states that—

It is known that for each acre to be irrigated in the San Joaquin Valley there should be about 3 acre-feet of water per year diverted from the river. The losses due to seepage from main canals and evaporation may be assumed to be included in the 3 acre-feet. It is probable that this allowance would make about 2.5 acre-feet per acre per year available in the irrigated field. This amount, whether this fact be admitted or not by the irrigator, will be adequate to provide the full measure of benefit that should come from the artificial application of water to the land.

Mr. Grunsky's estimate, then, is based upon net acreage, and a duty of water of 2.5 acre-feet is the measure of the water actually delivered in the field rather than at the point of diversion. Since it is probable that the reduction from gross to net acreage will approximately offset the reduction in flow through evaporation and seepage, Mr. Grunsky's estimate does not appear to be far from a duty of 2.5 acre-feet measured at the point of diversion for the gross acreage of irrigable land.

The irrigation requirement of 173,774,000,000 gallons per annum allowed by Mr. Williams is equivalent to 533,500 acre-feet per annum.

The estimate of the Geological Survey, indicated above, of 2½ acre-feet per acre for the gross area measured at diversion, is about the same as that estimated by Messrs. Crowe and Smith, engineers for the districts, namely, 2.75 acre-feet per acre for 90 per cent of the gross area. It is also substantially the same as that assumed by Mr. Wadsworth, although stated in somewhat different terms.

In addition to the duty of water indicated above, a small allowance has been made for evaporation from the surface of storage reservoirs, which are necessary in order to make available the total quantity of water needed for irrigation.

Monthly distribution of irrigation requirements.—While in general water rights on the streams discussed in this report are filed in terms of second-feet continuous flow, it is recognized that under the irrigation conditions existing in the San Joaquin Valley the quantity of water which will be required for irrigation purposes varies from month to month so that the irrigation demand may actually reach the amount filed upon only for a short period during the hottest part of the irrigation season. The various engineers who have studied irrigation requirements in the San Joaquin Valley have endeavored to approximate the quantity of water which would be required in the several months of the year in order that the actual demand for irrigation purposes might be estimated as closely as possible. Mr. Grunsky in his report on the Mokelumne River, the engineers of the Turlock-Modesto districts, Mr. H. H. Wadsworth, and Mr. Dockweiler have all assumed such distribution rates, and for comparative purposes the following table is presented in which has been compiled the demand indicated by each. The monthly demand is given in percentages of the total annual irrigation requirement.

Distribution of irrigation demand through the year.

Month.	Grunsky.		Wadsworth.		Dockweiler.		Crowe & Smith.	
	Per cent.	Cumulative sum.	Per cent.	Cumulative sum.	Per cent.	Cumulative sum.	Per cent.	Cumulative sum.
January	1.0	1.0	0.0	0.0	0.0	0.0	2.0	2.0
February	2.0	3.0	0.0	0.0	0.682	0.682	3.0	5.0
March	4.0	7.0	6.8	6.8	8.380	9.062	4.0	9.0
April	8.0	15.0	14.4	21.2	16.270	25.332	8.0	17.0
May	15.0	30.0	14.4	35.6	19.933	45.265	15.0	32.0
June	20.0	50.0	14.4	50.0	19.626	64.891	16.0	48.0
July	18.0	68.0	14.4	64.4	19.899	84.790	16.0	64.0
August	15.0	83.0	14.4	78.8	11.566	96.356	14.0	78.0
September	10.0	93.0	14.4	93.2	2.476	98.832	13.0	91.0
October	5.0	98.0	6.8	100.0	1.059	99.891	6.0	97.0
November	1.0	99.0	0.0	100.0	0.409	100.00	2.0	99.0
December	1.0	100.0	0.0	100.0	0.000	100.00	1.0	100.0
	100.00	.....	100.00	.....	100.00	.....	100.00	.....

In estimating the irrigation requirements the Geological Survey has adopted the percentages assumed by Mr. Grunsky.

Tuolumne River.—As above stated, the irrigable acreage under Tuolumne River has been fixed at 411,520 acres gross. With a duty of water measured at the point of diversion from the river of 2.5 acre-feet a total irrigation requirement of 1,028,800 acre-feet is indicated. If this amount is distributed throughout the irrigation season in accordance with the percentages used by Mr. Grunsky and 12,500 acre-feet additional is allowed to offset evaporation from storage reservoirs during each of the months May, June, July, and August, or 50,000 acre-feet in all for evaporation, the irrigation demand month by month in acre-feet is as follows:

Monthly irrigation requirements in acre-feet.

January	10,288	August	166,820
February	20,576	September	102,880
March	41,152	October	51,440
April	82,304	November	10,288
May	166,820	December	10,288
June	218,260		
July	197,684	Year	1,078,800

If the irrigation requirement above stated is applied to the record of run-off for Tuolumne River at La Grange for the period December, 1895, to September 15, 1913, the amount of surplus or deficit for consecutive portions of this period is shown in the following table:

Surplus and deficiency in the unregulated flow of Tuolumne River as a result of irrigation requirements.

Period.	Surplus.	Deficit.
September to November, 1895	.....	134,044
December, 1895, to June, 1896	783,267	.....
July, 1896, to October, 1896	.....	271,211
November, 1896, to June, 1897	1,715,970	.....
July, 1897, to October, 1897	.....	351,379
November, 1897, to May, 1898	447,950	.....
June, 1898, to November, 1898	.....	584,701
December, 1898, to June, 1899	706,530	.....
July, 1899, to October, 1899	.....	414,790
November, 1899, to June, 1900	991,070	.....

Surplus and deficiency in the unregulated flow of Tuolumne River as a result of irrigation requirements—Continued.

Period.	Surplus.	Deficit.
July, 1900, to September, 1900		421,413
October, 1900, to July, 1901	1,850,121	
August, 1901, to October, 1901		249,547
November, 1901, to June, 1902	918,129	
July, 1902, to October, 1902		396,962
November, 1902, to June, 1903	1,296,276	
July, 1903, to October, 1903		404,481
November, 1903, to June, 1904	1,828,124	
July, 1904, to September, 1904		198,685
October, 1904, to June, 1905	1,008,301	
July, 1905, to December, 1905		424,642
January, 1906, to July, 1906	2,609,916	
August, 1906, to October, 1906		143,840
November, 1906, to July, 1907	2,823,240	
August, 1907, to October, 1907		140,940
November, 1907, to May, 1908	436,584	
June, 1908, to October, 1908		446,984
November, 1908, to July, 1909	1,836,640	
August, 1909, to October, 1909		195,260
November, 1909, to May, 1910	1,445,284	
June, 1910, to October, 1910		454,884
November, 1910, to July, 1911	2,563,240	
August, 1911, to November, 1911		234,020
December, 1911, to June, 1912	396,612	
July, 1912, to October, 1912		428,684
November, 1912, to June, 1913	390,924	
July, 1913, to Sept. 15, 1913		291,000

From this table it is observed that for every period except that from June, 1898, to November, 1898, and July, 1912, to October, 1912, the preceding period had sufficient surplus flow to provide for the dry period following. In these two periods, however, stored water would have been carried over from the preceding year, in the first instance to the amount of 137,000 acre-feet and in the second instance to the amount of 65,000 acre-feet. The amount of the individual deficits given in the table, however, represents the amount of storage required in each year of record and includes the two periods which are recognized as the lowest in precipitation and water supply in the history of irrigation in the San Joaquin Valley. In the extreme year 1898 a maximum storage of 584,700 acre-feet would have been required. In only one other year—1910—did the amount of storage necessary exceed 450,000 acre-feet, and then only slightly. In six other years storage of 400,000 acre-feet or more would have been necessary to meet completely irrigation demands on the basis assumed. Since in a period of 24 years covered by stream measurements on Tuolumne River, and in a much longer period covered by rainfall observations in the San Joaquin Valley, no other year as severe as 1898 has been experienced, it is thought unnecessary to place the storage requirement for irrigation at the extreme of 580,000 acre-feet indicated for that year. A storage of 450,000 acre-feet will meet irrigation requirements in all but two years of the 18-year period analyzed, and this amount is believed by the Geological Survey to be a proper amount of storage to provide for irrigation purposes on this river. The assumed evaporation from the surface of storage reservoirs represents, therefore, about 10 per cent of the total storage requirements and is equivalent to an evaporation of 4 feet in depth on an average area of reservoir surface of 12,500 acres. Since by far the greater part of this evaporation comes in the summer season, it has, for purposes of estimate, been divided equally between the

months of May, June, July, and August, during which the water surface in the reservoirs will be the largest and the evaporation will also be at its maximum.

Stanislaus River.—Similarly, in the case of Stanislaus River a gross irrigable area of 240,000 acres has been assumed, which with a diversion duty of 2½ acre-feet would require 600,000 acre-feet of water per annum and an additional allowance of 30,000 acre-feet to offset evaporation from the surface of storage reservoirs. The following distribution throughout the year is based on Mr. Grunsky's percentages:

Monthly irrigation requirement in acre-feet.

January	6,000	August	97,500
February	12,000	September	60,000
March	24,000	October	30,000
April	48,000	November	6,000
May	97,500	December	6,000
June	127,500		
July	115,500	Year	630,000

Applying these irrigation requirements to the record of discharge of the Stanislaus River at Knights Ferry for the periods of June, 1895, to December, 1900, and May, 1903, to September, 1913, the amount of surplus or deficit resulting after irrigation requirements have been met is indicated in the following table:

Surplus and deficiency in the unregulated flow of Stanislaus River as a result of irrigation requirements.

Period.	Surplus.	Deficit.
June, 1895, to October, 1895		124,594
November, 1895, to June, 1896	877,669	
July, 1896, to October, 1896		165,338
November, 1896, to May, 1897	971,841	
June, 1897, to October, 1897		239,082
November, 1897, to April, 1898	115,830	
May, 1898, to November, 1898		383,855
December, 1898, to June, 1899	410,030	
July, 1899, to October, 1899		238,852
November, 1899, to May, 1900	536,521	
June, 1900, to October, 1900		263,969
November and December, 1900	14,151	
May and June, 1903	204,162	
July, 1903, to October, 1903		250,308
November, 1903, to June, 1904	1,567,098	
July, 1904, to September, 1904		154,970
October, 1904, to June, 1905	433,981	
July, 1905, to November, 1905		244,579
December, 1905, to July, 1906	1,857,555	
August, 1906, to October, 1906		101,200
November, 1906, to July, 1907	2,256,400	
August, 1907, to October, 1907		82,400
November, 1907, to May, 1908	245,700	
June, 1908, to October, 1908		291,290
November, 1908, to June, 1909	1,438,730	
July, 1909, to October, 1909		172,780
November, 1909, to May, 1910	1,006,000	
June, 1910, to October, 1910		273,600
November, 1910, to July, 1911	1,810,700	
August, 1911, to October, 1911		117,800
November, 1911, to June, 1912	179,500	
July, 1912, to October, 1912		236,000
November, 1912, to May, 1913	194,190	
June, 1913, to September, 1913		254,200

As in the case of the Tuolumne River, it may be observed from the above table that the two critical periods have occurred in 1898 and 1912–13. The period of May–November, 1898, when a deficiency of

383,855 acre-feet was shown, was preceded by a period of extremely low run-off, November, 1897–April, 1898, when a surplus of only 115,830 acre-feet appears to have been available under the irrigation requirement assumed. To meet this deficiency, then, it would have been necessary to carry over stored water from the period November, 1896–May, 1897, and through the deficiency period June, 1897–October, 1897. In order that the irrigation requirements might have been fully met a storage capacity of 507,000 acre-feet would have been necessary.

After the period of high run-off, extending from March, 1910, to July, 1911, in which a surplus of 1,810,700 acre-feet is indicated, a deficiency would arise in the next three months of 117,800 acre-feet. The following period, November, 1911, to June, 1912, while one of comparatively small run-off, is well adjusted to irrigation requirements, so that no deficiency occurs in this period although only 179,500 acre-feet is available as surplus. This amount, however, would more than refill the reservoirs depleted by the deficiency of the previous three months, August to October, 1911. At the end of the period November, 1911, to June, 1912, then, irrigation reservoirs would have been full. The following periods, July to October, 1912, and November, 1912, to May, 1913, show, respectively, a deficiency of 236,000 and a surplus of 194,990. In this case the surplus available does not make up for the deficiency caused during the previous period of maximum demand for irrigation and the reservoirs would then lack over 40,000 acre-feet of being full. The following period, June to October, just passed, shows a further estimated deficiency of 264,000 acre-feet, so that the amount of storage necessary to carry irrigation through the period appears to have been about 305,000 acre-feet. From an irrigation standpoint this last period of drought does not appear to have been as severe as the period in 1898.

Aside from these periods the irrigation deficiency which must be offset by storage does not in any year exceed 300,000 acre-feet, although in seven other years besides those just discussed the amount of storage required would have been over 200,000 acre-feet.

Taking into consideration these deficiencies as indicating what would have been the requirements for irrigation storage in the past, it is believed that reasonable irrigation requirements on the stream would be satisfactorily taken care of if storage were provided to the amount of 300,000 acre-feet. In the 24-year period of record on the Stanislaus River this amount of storage would have fully satisfied irrigation requirements in all except two years, in the latter of which the deficiency would have been comparatively slight. In the one year of extreme drought—1898—a shortage of approximately 200,000 acre-feet would have occurred, reducing the water supply available for irrigation to 21 inches in depth on the land instead of 30 as in normal years.

An allowance of 10 per cent, or 30,000 acre-feet, has been made to offset evaporation from storage reservoirs and is included in the 300,000 acre-feet proposed.

Mokelumne River.—The assumed irrigable area of 225,000 acres proposed to be irrigated from Mokelumne River will require 562,500 acre-feet of water per annum to supply 2.5 acre-feet for each acre of the gross area measured at the point of diversion from the river.

Assuming the same distribution of the water throughout this irrigation season as has been used for the Tuolumne and Stanislaus Rivers, the following table has been prepared to indicate the amount of water required for each month in the year. An additional 7,500 acre-feet has been included in May, June, July, and August, to offset evaporation from storage reservoirs during these months.

Monthly irrigation requirements in acre-feet.

January	5,625	August	91,875
February	11,250	September	56,250
March	22,500	October	28,125
April	45,000	November	5,625
May	91,875	December	5,625
June	120,000		
July	108,750	Year	592,500

The records of run-off for Mokelumne River, except for two broken periods in 1901 and 1903–4, extend from January, 1905, to September, 1913. Applying the irrigation requirements above stated to the record of run-off of the river, the following figures are obtained, representing the surplus and deficiency for consecutive periods of the record:

Surplus and deficiency in the unregulated flow of Mokelumne River as a result of irrigation requirements.

Period.	Surplus.	Deficit.
January, 1905, to May, 1905	257,390	.....
June, 1905, to November, 1905	.....	272,119
December, 1905, to July, 1906	896,440	.....
August, 1906, to October, 1906	.....	130,650
November, 1906, to July, 1907	1,185,550	.....
August, 1907, to October, 1907	.....	100,750
November, 1907, to June, 1908	127,400	.....
July, 1908, to October, 1908	.....	247,740
November, 1908, to June, 1909	768,780	.....
July, 1909, to October, 1909	.....	214,570
November, 1909, to May, 1910	632,300	.....
June, 1910, to October, 1910	.....	319,940
November, 1910, to July, 1911	1,760,750	.....
August, 1911, to October, 1911	.....	141,680
November, 1911, to January, 1912	17,385	.....
February, 1912, to April, 1912	.....	16,150
May and June, 1912	53,125	.....
July, 1912, to October, 1912	.....	257,640
November, 1912, to February, 1913	55,875	.....
March, 1913	.....	900
April and May, 1913	95,025	.....
June, 1913, to September, 1913	.....	296,345
October, 1913 (estimated)	.....	23,000

By methods of computation similar to those previously used it appears that for the period extending from August, 1911, to October, 1913, storage to the amount of 515,000 acre-feet would have been required to satisfy fully irrigation requirements on the area assumed. The irrigation season of 1898, which has been shown to have been most deficient in water supply on Tuolumne and Stanislaus Rivers, is not covered by the record of stream measurements on Mokelumne River. The period of July to October, 1910, also shows a serious deficiency amounting to 319,940 acre-feet. Aside from these periods the limited record shows no irrigation deficiency of over 275,000

acre-feet. While it is realized that there would be a serious shortage for irrigation in the season which has just closed, it is believed that irrigation storage on this river is not justified to an amount in excess of 300,000 acre-feet, and this amount has been adopted for the purposes of this report.

The allowance of 30,000 acre-feet in the months of May, June, July, and August, above mentioned, is equivalent to 10 per cent of the total irrigation storage assumed and is included in the 300,000 acre-feet.

Cosumnes River.—The records of stream flow on Cosumnes River cover the period from October, 1907, to September, 1913, gagings being taken at Michigan Bar, where the drainage area is 536 square miles. Records published by the engineering department of the State of California for the period from November, 1878, to October, 1884, are based entirely on computed run-off from adjacent drainage basins. The comparison of the recent records of actual discharge at Michigan Bar with the early estimates indicates that the engineering department of the State of California assumed incorrect relations between Cosumnes River and the adjoining basins, with the result that their estimates of discharge for that early period were too high. The mean for the early period was estimated as 921,000 acre-feet per annum, whereas the actual measurements for the recent period of six years show a mean of only 388,000 acre-feet. The adjacent streams in California for the same recent period show a mean discharge practically the same as the mean discharge for the earlier period for which estimates of the Cosumnes were made.

In computing the irrigation requirements for Cosumnes River, an irrigable acreage of 100,000 acres has been assumed. This acreage with a duty of 2½ acre-feet per annum, measured at the point of diversion and distributed throughout the year on the same basis as was adopted for the Stanislaus, Mokelumne, and Tuolumne, gives an irrigation demand in acre-feet month by month as indicated in the following table:

Monthly irrigation requirements, in acre-feet.

January	2,500	August	37,500
February	5,000	September	25,000
March	10,000	October	12,500
April	20,000	November	2,500
May	37,500	December	2,500
June	50,000		
July	45,000	Year	250,000

The irrigation demands so computed month by month have been applied to the records of discharge of Cosumnes River at Michigan Bar for the period from 1907 to date, and the following computations of surplus and deficiency were made:

Surplus and deficiency in the unregulated flow of Cosumnes River as a result of irrigation requirements.

Period.	Surplus.	Deficit.
November, 1907, to April, 1908	74,500	.....
May, 1908, to November, 1908	.....	178,016
December, 1908, to May, 1909	538,800	.....
June, 1909, to October, 1909	.....	148,101
November, 1909, to April, 1910	385,400	.....
May, 1910, to October, 1910	.....	172,872
November, 1910, to May, 1911	731,840	.....
June, 1911, to October, 1911	.....	103,790
November, 1911, to May, 1912	34,610	.....
June, 1912, to October, 1912	.....	147,678
November, 1912, to April, 1913	47,060	.....
May, 1913, to September, 1913	.....	158,238

This table indicates that in years of ordinary run-off storage of about 175,000 acre-feet will be required, but during the extreme period from June, 1911, to September, 1913, much additional storage would be necessary. A comparison of the figures indicates that for the periods from November, 1911, to May, 1912, and November, 1912, to April, 1913, the surplus over irrigation requirements is entirely inadequate to supply the storage demands of the next succeeding periods. In consequence, water for the irrigation periods in 1912 and 1913 must have been stored from the last previous period of excess, namely, November, 1910, to May, 1911. Making no allowance for evaporation and seepage, the total storage required fully to meet irrigation requirements throughout this dry period would have been 328,000 acre-feet. Records are not available on Cosumnes River for the dry period extending from October, 1897, to September, 1898; but as Cosumnes River does not reach the crest of the Sierras but drains an area situated largely in the foothills, it is believed that this dry period was probably as severe as the period just discussed.

Since it is necessary to store water over a period of two years to meet fully irrigation requirements on Cosumnes River, a much larger proportional storage is necessary than on the adjacent larger streams, and because of this long storage period evaporation from the reservoirs would be relatively great. In fact, for the period from November, 1911, to September, 1913, it is probable that the apparent surplus in supply during the first half of each year would have been entirely consumed in evaporation losses in the reservoirs, so that the draft on storage for that period would really have been much greater than indicated in the table. It appears, then, that in at least the two most recent years of record the assumed irrigation demands are largely in excess of the run-off of the drainage basin, and that, with complete development of irrigation in the San Joaquin Valley, Cosumnes River, considered by itself, will be entirely required for the irrigation of lands located under it, leaving no dependable surplus for water supply for incorporated cities and towns. In considering the Cosumnes as a source of municipal water supply it has generally been taken in connection with the adjacent American River in connection with a scheme for diverting water from the American to store in reservoir sites located on the Cosumnes, but this possibility does not enter into the present discussion since it is the understanding of the Geological Survey that, in answering the questions contained in the resolution, the Cosumnes must be considered independently.

WATER SUPPLIES FOR INCORPORATED CITIES AND TOWNS.

Available drainage areas.—While the Senate resolution is general in terms and does not indicate for what incorporated cities and towns the estimated water supply is to be used, yet in view of the debates in Congress which have preceded this resolution and of bills pending in Congress granting rights to San Francisco in the upper Tuolumne watershed, it is assumed for purposes of this report that the term "incorporated cities and towns" has reference to the metropolitan area adjacent to San Francisco Bay. The supplying of the needs in this metropolitan area from Sierra sources will require an aqueduct crossing the San Joaquin Valley and the Coast Ranges, the former most feasibly by siphon and the latter necessarily by tunnel of some practicable elevation and length. The city of San Francisco has devoted much time to the study of feasible tunnel locations throughout the Coast Ranges and has determined upon a tunnel with the east portal 75 miles from the city at an elevation of approximately 374 feet. The hydraulic gradient at this point is, however, at elevation 470 for a supply of 400,000,000 gallons per day. To deliver the water at this point and under this head on the western side of San Joaquin Valley through a siphon, approximately 40 miles long, requires the hydraulic gradient at the entrance of the siphon on the east of the valley to reach an elevation of 770 feet, assuming the size and length of siphon to be the same irrespective of the source of the water.

On the conduit proposed in Freeman's report the hydraulic gradient of 770 feet is reached at mile 122, measuring from the city. Extending this hydraulic gradient eastward it is found that it approaches the level of Tuolumne River at approximately mile 144 of the proposed conduit. At the mouth of the North Fork of Tuolumne River the hydraulic gradient would attain an elevation of about 920 feet. The level of the Tuolumne River at the mouth of the North Fork is 840 feet, so that in order to deliver a supply for municipal purposes at this point at the required elevation a diversion dam approximately 90 feet high would have to be constructed. Since the river is in a narrow canyon this appears to be entirely feasible. The drainage area above this point is 1,257 square miles. Practically all of the area lies within the boundaries of the Stanislaus and other national forests. The Tuolumne River and the North Fork above this proposed diversion are situated in steep canyons in which there are at the present time no roads and but little settlement.

If the hydraulic gradient proposed by Mr. Freeman in connection with the conduit from the Tuolumne be projected to the Stanislaus River it is found that at the proposed Robinson Reservoir (mile 134) a hydraulic gradient of approximately 920 feet will be required to deliver water on the west side of San Joaquin Valley at the level proposed for the tunnel through the Coast Range. The water line of Robinson Reservoir as proposed would have an elevation of 1,000 feet, so that the upper 80 feet of the reservoir would be available for storage, in addition to furnishing a proper elevation for diversion to the conduit. The drainage area above Robinson Reservoir is 827 square miles.

The elevation of tail water at the present hydroelectric plant at Electra on the Mokelumne River is approximately 800 feet. This

power plant utilizes at the present time all of the low-water flow of the river. This elevation appears to be slightly lower than that which would probably be required for an intake for a conduit for city water supply. Projecting the hydraulic gradient eastward from the portal of the Coast Range Tunnel, it appears that a diversion at Electra would probably have to be made at about 850 feet, so that there appears to be some conflict between existing power developments on the stream and a diversion for city water supply at this point.

For the purpose of determining the area drained by the Mokelumne from which a water supply for city use could be drawn, the diversion point has been placed tentatively at Electra, this being the lowest point on the river where the requisite hydraulic gradient could be obtained with a dam of moderate height. The drainage area above this point is 532 square miles.

The analysis of the water supply of the Cosumnes previously made indicates that if lands properly irrigable are supplied from the stream there will be practically no surplus for use as a water supply for incorporated cities and towns; hence it is considered that no portion of this drainage area is available for use by cities and towns of any considerable size.

Available run-off.—The total quantity of water in Tuolumne River which will be available for the use of incorporated cities and towns after allowance has been made for beneficial use of the lands properly irrigable from this source is 961,000 acre-feet per annum. This quantity is the mean annual run-off of the river at La Grange (2,040,000 acre-feet) less the requirements for irrigation (1,079,000 acre-feet). The difference, 961,000 acre-feet per annum, is equivalent to 858,000,000 gallons per day.

The total quantity of water in Stanislaus River which would be available for the use of incorporated cities and towns after proper allowance has been made for beneficial use of the lands properly irrigable from this river is 750,000 acre-feet. This quantity has been determined by subtracting from the total mean annual discharge of the river at Knights Ferry (1,380,000 acre-feet) the quantity necessary for irrigation purposes; namely, 630,000 acre-feet. Seven hundred and fifty thousand acre-feet per annum is equivalent to 669,000,000 gallons per day.

Similarly, the quantity of water available in Mokelumne River for the use of incorporated cities and towns has been determined as 287,500 acre-feet, equivalent to 257,000,000 gallons per day, by subtracting from the total mean annual discharge at Clements (880,000 acre-feet) the quantity required for beneficial use of the lands properly irrigable from this river (592,500 acre-feet).

Capacity of storage available for city water supply.—As shown above in this report, the storage capacity available for use of incorporated cities and towns after allowance has been made for irrigation is, for Tuolumne River 550,000 acre-feet, for Stanislaus River 250,000 acre-feet, for Mokelumne 0, and for Cosumnes River 0.

City water supply made available by storage.—The proper limit of municipal supply which may be made available by means of a fixed storage capacity will be determined by the most severe period for which storage is required. For the rivers under consideration and within the periods of record of discharge of those rivers, the most

severe periods have been shown to be in 1897–98 and 1911–1913. If, then, the calculation is made of the amount of water which would have been made available for city use with the storage allotted for the purpose, and the result is expressed in terms of continuous flow, the amount of water which the river would furnish under the exacting conditions of a city water supply will have been determined. The following calculation, based on the recent period of deficient run-off of Tuolumne River, indicates that for this period the Tuolumne River is not dependable, with 450,000 acre-feet of storage for irrigation and 550,000 acre-feet of storage for city water supply, for more than 230,000,000 gallons per day.

The period, November, 1910, to July, 1911, inclusive, was one of high run-off, which aggregated 3,320,900 acre-feet. At the close of this period of excessive run-off all storage reservoirs considered feasible would have been full and there would have been in storage for irrigation 450,000 acre-feet, and for city water supply 550,000 acre-feet, During the ensuing period, the months of August to November, 1911. inclusive, the irrigation storage would have been drawn down an amount indicated on the balance sheet in a previous part of this report, 234,020 acre-feet. On December 1 the amount of water in the irrigation reservoirs would then have been reduced to 215,980 acre-feet. This reduction also includes allowance for evaporation. During the same period of four months the reservoirs devoted to city water supply would have been subject to a constant draft. If "x" equals the amount of monthly draft for city use, and evaporation during the late summer from the city reservoirs is placed at 25,000 acre-feet, the amount of storage in the city reservoirs on December 1 would be 550,000 acre-feet $-25{,}000-4\,x$. During the period December 1, 1911, to June, 1912, immediately following, the surplus flow over irrigation requirements as indicated above was 396,612 acre-feet. This amount would replenish irrigation reservoirs drawn down in the previous period to their full capacity of 450,000 acre-feet and leave 162,592 acre-feet available for storage for city supply. During these seven months there would have been a constant draft represented by $7\,x$, so that on July 1, 1912, the amount of water in storage available for city water supply would have been equivalent to $712{,}592-25{,}000-11\,x$. In the next period, July to October, 1912, irrigation requirements would draw on irrigation storage to the amount of 428,684 acre-feet, so that on November 1, 1912, only 31,316 acre-feet would remain in irrigation storage. During these four months there would be no water available from direct flow for city use and storage would have been drawn on to the extent of $4\,x$, together with 50,000 acre-feet allowance for evaporation. The status of the city reservoirs on November 1, 1912, would then be $712{,}592-15\,x-75{,}000$. The next period, November, 1912, to June, 1913, shows a surplus from direct flow over irrigation requirements during this period of 390,924 acre-feet. Since irrigation would have priority, this amount would be taken up by irrigation storage, increasing the amount of water in the irrigation reservoirs to 422,240 acre-feet, allowance having been previously made for evaporation. There would, however, be no surplus water to store in city reservoirs, and there would be another draft during this period of $8\,x$. On July 1, 1913, there would then have been 422,240 acre-feet in storage for irrigation, while the amount in storage for city use would have been

equivalent to $712{,}592-23\,x-75{,}000$. The next period, July 1 to October 30, 1913, would show an estimated irrigation deficit of 291,000 acre-feet which would have been drawn from irrigation storage, leaving 131,240 acre-feet in storage for irrigation on November 1, 1913. During this period there would have been no water whatever in the direct flow of the river for city use, and, basing the prediction on the flow of the river in the previous year, this condition would have continued until January 1, 1914. There would then in the 6 months' period have been an additional draft on the city supply of $6\,x$, together with 15,000 acre-feet additional, estimated evaporation from city storage. The condition of storage in the city reservoirs on January 1, 1914, would be represented by $712{,}592-90{,}000-29\,x$. If we assume that the reservoirs are empty on that date then we have the equation $712{,}592-90{,}000-29\,x=0$. Then $x=21{,}469$, the amount of water in acre-feet per month which the city might have drawn during the period from August 1, 1911, to January 1, 1914. This amount is equivalent to 233,000,000 gallons per day draft over the entire period of 29 months.

By similar computations for the period of 19 months from July 1, 1897, to January 30, 1899, the amount available appears to have been 313,000,000 gallons per day. The recent period of shortage is thus found to be the most serious from the standpoint of city water supply, after full allowance has been made for irrigation requirements.

In the case of the Stanislaus similar computations indicate that in the low periods, 1911–1914 and 1897–98, corresponding to those discussed for the Tuolumne, the Stanislaus would, with the storage available, have furnished 100,000,000 and 117,000,000 gallons per day, respectively.

The Mokelumne and Cosumnes have no feasible storage sites in excess of irrigation requirements; hence, under the conditions imposed by the resolution, would in these low periods have been unable to furnish a constant flow of any amount for city water supply.

CHERRY, LAKE ELEANOR, AND HETCH HETCHY TRIBUTARIES.

The average annual flow of water of Cherry, Lake Eleanor, and Hetch Hetchy tributaries as determined by a comparison of the short records of these streams with the long time records at Lagrange is set forth in the following table:

	Acre-feet.
Cherry Creek at Groveland	295,000
Eleanor Creek at Groveland	146,000
Tuolumne at Hetch Hetchy dam site	805,000

It has been impossible for the survey within the time available for the preparation of this report to secure the data and make the analyses necessary for estimating the amount of hydroelectric power which may be developed in each of these three tributaries of the Tuolumne. The engineers of the survey have no reason to disagree, however, with the general estimates of power possibilities prepared by Mr. Freeman, Mr. Wadsworth, and other engineers who have made exhaustive studies of these streams and whose reports have been submitted in connection with the application of the city of San

Francisco for reservoir sites and rights of way for a municipal water supply.

Transmitted herewith is a large scale map showing the drainage areas and principal reservoir sites discussed, a small index map, and a diagram showing graphically records of the run-off called for by the resolution. The portions of the hydrograph colored black represent the requirements of irrigation which will be fully met from normal flow and the cross-hatched portions represent irrigation requirements for which stored water will be necessary.

The compilation and analysis of the data presented in this report have been made by Messrs. N. C. Grover and W. B. Heroy.

Respectfully,

GEORGE OTIS SMITH, *Director.*